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Extended cascade models of age and individual differences in children's fluid intelligence

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ABSTRACT

Children's cognitive abilities (e.g., processing speed, working and secondary memory, and fluid intelligence) improve with age, but the relationships among these abilities are not well understood. According to the developmental cascade model proposed by Fry and Hale (1996), age-related improvements in processing speed lead to improvements in working memory, which in turn lead to improvements in fluid intelligence. Recent research in adults suggests that secondary memory also plays an important role in fluid intelligence, but its role in children has received little attention. Accordingly, the current study examined the roles of speed, working memory, secondary memory, and fluid intelligence in a sample of 113 children between the ages of 6–12 years. Results indicated that secondary memory affected fluid intelligence indirectly by mediating the relations between speed and working memory, but only working memory accounted for significant unique variance in children's fluid intelligence.

1. Introduction

Children's cognitive abilities, including processing speed, memory, and fluid intelligence, all improve with age (Kail, 2007). However, the nature of the relations among these developmental trends is not well understood. According to the developmental cascade model proposed by Fry and Hale (1996), age-related increases in processing speed lead to improved working memory, which in turn positively affects performance on tests of fluid intelligence. Thus, according to the model, both age-related and individual differences in working memory mediate the relationship between processing speed and fluid intelligence. Results consistent with Fry and Hale's (1996) cascade model have been obtained in several cross-sectional and longitudinal studies (de Ribaupierre & Lecerf, 2006; Demetriou, Constantinos, Spanoudis, & Platsidou, 2002; Kail, 2007; Nettelbeck & Burns, 2010), providing further evidence that the development of working memory is a key component of age-related improvements in children's fluid intelligence.

Kail and Salthouse (1994) proposed that the reason why age-related changes in processing speed affect higher cognitive abilities is because of the effects of speed on working memory. More specifically, Salthouse (1996) hypothesized that faster processing improves working memory by making it possible to complete necessary cognitive operations either when environmental constraints restrict the time that information is available (which he termed the *limited-time* mechanism), as when processing spoken language, or when the availability of information is limited because of internal constraints such as forgetting due to decay or interference (which he termed the *simultaneity* mechanism), as in situations that require multi-tasking. Better working memory, in turn, is believed to be necessary for higher cognitive tasks like fluid reasoning (Carpenter, Just, & Shell, 1990). In addition, performance on working

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memory tasks has been hypothesized to predict fluid intelligence because both depend on executive functions like the ability to control attention (Engle, Tuholski, Laughlin, & Conway, 1999), and, more recently, because working memory tasks and reasoning tests both require maintaining information in primary memory and, more importantly, retrieving information from secondary memory (Unsworth & Engle, 2007).

Baddeley and Hitch (1974) proposed that the working memory system consists of both a domain-general executive component and domain-specific storage components, one for verbal information and one for visuospatial information, and a multi-modal store has recently been added to the Baddeley model (Repovs & Baddeley, 2006). Several recent studies (Engel de Abreu, Conway, & Gathercole, 2010; Hornung, Brunner, Reuter, & Martin, 2011; Tillman, Nyberg, & Bohlin, 2008) have attempted to divide children's working memory ability into executive and storage functions based on performance on simple and complex span tasks (Engle et al., 1999). The goal of these studies was to determine which components are responsible for the relationship between working memory and fluid intelligence in children, but Engel de Abreu et al. (2010), Hornung et al. (2011), and Tillman et al. (2008) each reached a different conclusion. A similar lack of consensus existed in the adult intelligence literature (for example, compare Colom, Rebollo, Abad, & Shih, 2006, with Conway, Cowan, Bunting, Therriault, & Minkoff, 2002), and indeed, more recent research has called into question the utility of trying to distinguish the contributions of storage and executive components (Hale et al., 2011; Unsworth & Engle, 2007). Instead, Unsworth and Engle have proposed a dual-component model which posits that working memory involves both maintaining information in primary memory and retrieving information from secondary memory.

According to Unsworth and Engle (2007), primary memory refers to information currently in the focus of attention (Cowan, 1999), whereas secondary memory consists of information that is outside the focus of attention and which therefore needs to be retrieved. As already noted, Unsworth and Engle (2007) hypothesized that individual differences in retrieving information from secondary memory are the principal reason why working memory measures, including both complex span tasks and memory for longer series of items on simple span tasks, do a good job of predicting fluid intelligence, at least in adults. Consistent with this view, performance on secondary memory tasks is a reliable predictor of adult fluid intelligence (Mogle, Lovett, Stawaski, & Sliwinski, 2008; Shelton, Elliot, Matthews, Hill, & Gouvier, 2010; Unsworth, Brewer, & Spillers, 2009).

While the role of secondary memory in crystallized intelligence is obvious, the role of secondary memory in fluid intelligence is less clear. However, it has been hypothesized that in fluid reasoning, partial solutions to a problem often need to be displaced from primary memory to work on the remaining parts of the problem and finally all components need to be retrieved from secondary memory to create the complete solution (De Alwis, Myerson, Hershey, & Hale, 2009; Unsworth & Engle, 2007). Moreover, past solutions and the rules on which they were based may need to be retrieved in order to solve current and future reasoning problems (Tamez, Myerson, & Hale, 2012).

De Alwis et al. (2009) were the first to explore the relationship between children's secondary memory and fluid intelligence in the context of Unsworth and Engle's (2007) dual-component model, and found that as predicted by the model, reasoning ability was significantly correlated with both immediate and delayed recall of information from secondary memory in children (ages 6–12 years). Prior to the present effort, however, the roles of working memory and secondary memory have not both been explored in a single study in children.

Although secondary memory is a component of working memory according to Unsworth and Engle (2007), it can also be assessed independent of that role by using supraspan lists and delayed recall (e.g., De Alwis et al., 2009; Unsworth et al., 2009). This was the approach used in the current study, in which we tested hypotheses based on two different findings relating secondary memory, working memory, and fluid intelligence in young adults. Hypothesis 1 was based on the work of Mogle et al. (2008), who suggested that in young adults at least, secondary memory explains all of the variance in fluid intelligence accounted for by working memory as well as additional unique variance. Hypothesis 2 was based on the findings of Shelton et al. (2010), who reported that, contrary to Mogle et al., secondary memory does not explain any variance in young adults' fluid intelligence that cannot also be accounted for by working memory, while working memory explains variance over and above that explained by secondary memory. A third possibility, of course, is that, as observed in Unsworth et al. (2009) study of young adults, both working memory and secondary memory make unique contributions to predicting fluid intelligence.

Prior to examining these possibilities, however, we considered a simpler alternative: a common factor model similar to models proposed to account for age-related cognitive differences in adults (e.g., Baltes & Lindenberger, 1997; Verhaeghen & Salthouse, 1997). Such models are appealing because they are conceptually parsimonious, positing that all age-related changes in cognition reflect the effects of a single common cause. After testing the common cause hypothesis, we proceeded to evaluate Hypotheses 1 and 2 (above) as instantiated in two extended developmental cascade path models, one in which secondary memory mediates the relation between working memory and fluid intelligence and another in which secondary memory mediates the relation between speed and working memory. The first extended cascade would appear to be more consistent with the modal model of memory, in which information passes through short-term or working memory on its way to long-term or secondary memory (Atkinson & Shiffrin, 1968), whereas the second would be more consistent with the Unsworth and Engle (2007) two-component model in which secondary memory is one component of working memory. Using both extended cascade models should reveal whether one of them provides a better description of the relations among the constructs, and if so, which one. In addition, comparing models should provide for a more rigorous test of our two primary hypotheses concerning the relative contributions of working memory and secondary memory ability to fluid intelligence in children.